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AN ITERATIVE PROCEDURE TO ESTIMATE MINIMUM VENT SIZES FOR CRYOGENIC CONTAINMENT VESSELS

by
Barry F. Battista, B. Lawrence Chesser, and Alok K. Majumdar
Sverdrup Technology Inc. MSFC Group
Huntsville, Alabama

and
Dalton Nguyen and James W. Owen
Marshall Space Flight Center
Huntsville, Alabama

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Abstract

An iterative procedure was established to determine the minimum diameter for a vent fitted atop a thin-walled, un-insulated cryogenic containment vessel. Because wall thicknesses of less than 0.5-inch (12.7 mm) and/or the absence of applied insulation give rise to high rates of steady state heat leakage, predicting minimum vent sizes is a matter of importance to designers of all such vessels. The vent must be of sufficient diameter, given a predetermined length and pipe configuration, to release vapor at a rate equal to that at which it is produced by boiling. If the diameter is less than some critical value, the equilibrium pressure within the tank must increase, possibly to a value exceeding a safe limit for the vessel.

The subject of the present investigation was a vertically configured, cylindrical, stainless-steel vessel, with a uniform wall thickness of 9/16-inch (14.3 mm). Constructed as an integral part of a test facility at the Marshall Space Flight Center, this tank was erected to store 10000 gallons (37900 l.) of saturated liquid Nitrogen at pressures to 100 psia (687 kPa). The tank appears in the facility schematic shown in Figure 1. This vessel was not insulated, nor was it shaded from direct solar radiation; hence, considerable effort was devoted to certifying an existing vent for an application wherein the anticipated vapor generation rate was very high. The vent assembly is depicted in Figure 2.

The rate of steady state heat leakage was estimated using the Systems Improved Numerical Differencing Algorithm (SINDA). A discretized model of a unit-area section of the tank wall was considered in this portion of the analysis. Because SINDA is a network analyzer, "convection conductors" were required for interior and exterior surfaces of the modeled section. Interior convection conductors were derived from appropriate boiling heat transfer coefficients; these coefficients were estimated using empirical correlations generated from data compiled for Nitrogen boiling on vertical and horizontal surfaces. Exterior convection conductors were determined for assumed ambient conditions (i.e. pressure, temperature, and wind speed) and were defined using a correlation suggested for a cylinder in cross flow. Net radiative heat transfer to the tank was considered.

Having estimated the rate of heat addition, a corresponding vapor generation rate was calculated. The aforementioned iterative procedure was then used to determine the vent diameter for which

the exit Mach number was unity, given the computed rate of vapor generation, a constant tank pressure, and a computed equivalent pipe length. This procedure entailed calculating a critical pipe diameter by executing the following sequence of steps: 1) assume an aspect ratio (L_{eq}/d) for the vent, 2) assume an exit Mach number of unity, 3) solve the appropriate compressible flow equations to determine a corresponding pipe diameter, 4) compute a new aspect ratio from the diameter determined in step three, 5) compare the assumed and computed aspect ratios and adjust (if necessary) the "assumed" value of the aspect ratio in preparation for the subsequent iteration. In essence, a choked flow condition was imposed at the discharge plane of the vent; this fixed exit condition was used to identify the smallest pipe through which a known mass of vapor must flow (per unit time) to maintain the assumed tank pressure. For the geometry considered in the present study, minimum vent diameters of 2.82, 1.51, and 1.23-inches (71.6, 38.4, and 31.2 mm) were reported for tank pressures of 14.7, 60, and 100 psia (101, 412, and 687 kPa), respectively. While the reported results are case specific, the general approach is universal and may be applied to most cases in which a homogeneous saturated vapor is expelled from a vented tank.

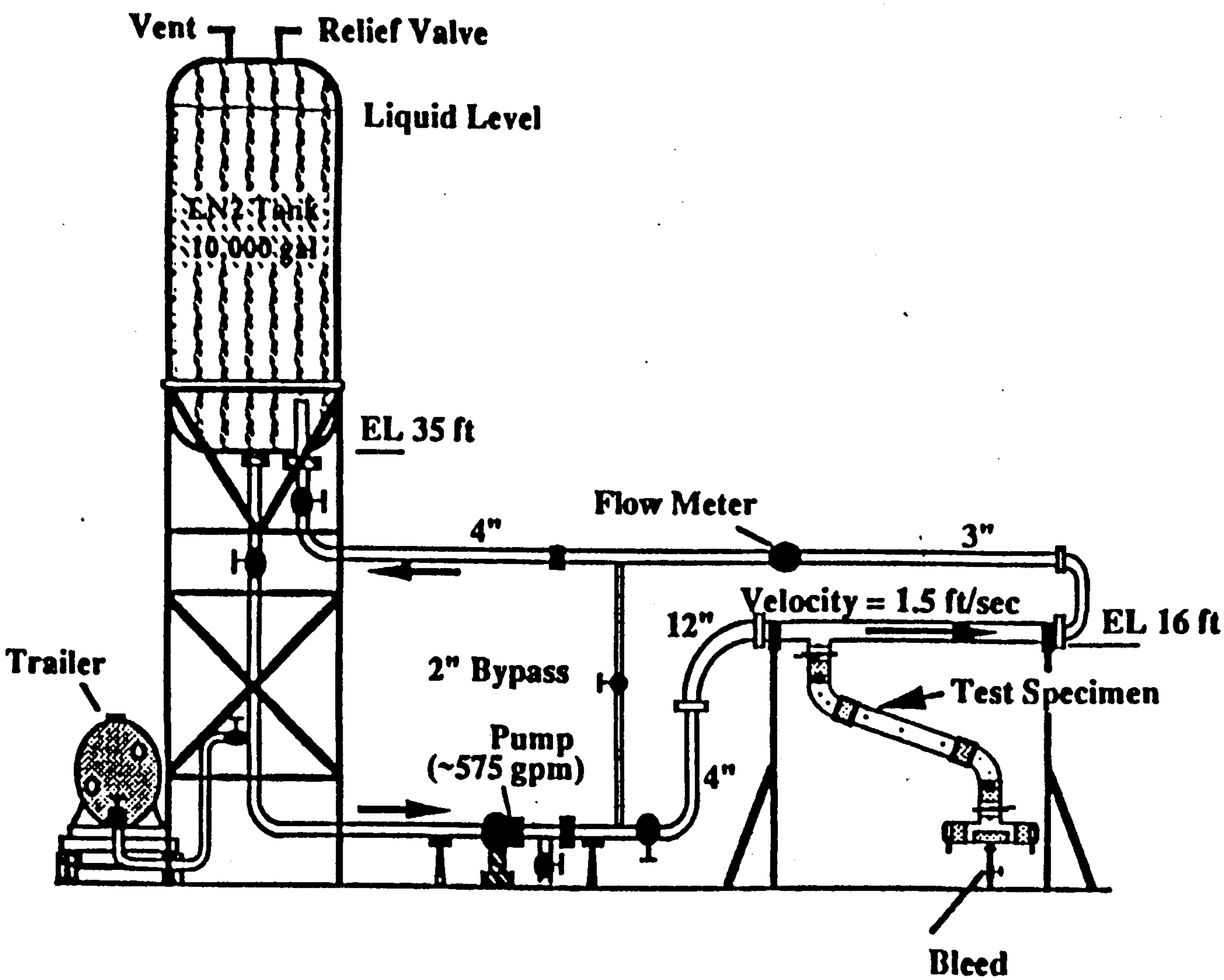

Figure 1. Schematic of test facility constructed at the Marshall Space Flight Center; storage tank is noted at upper-left of schematic.

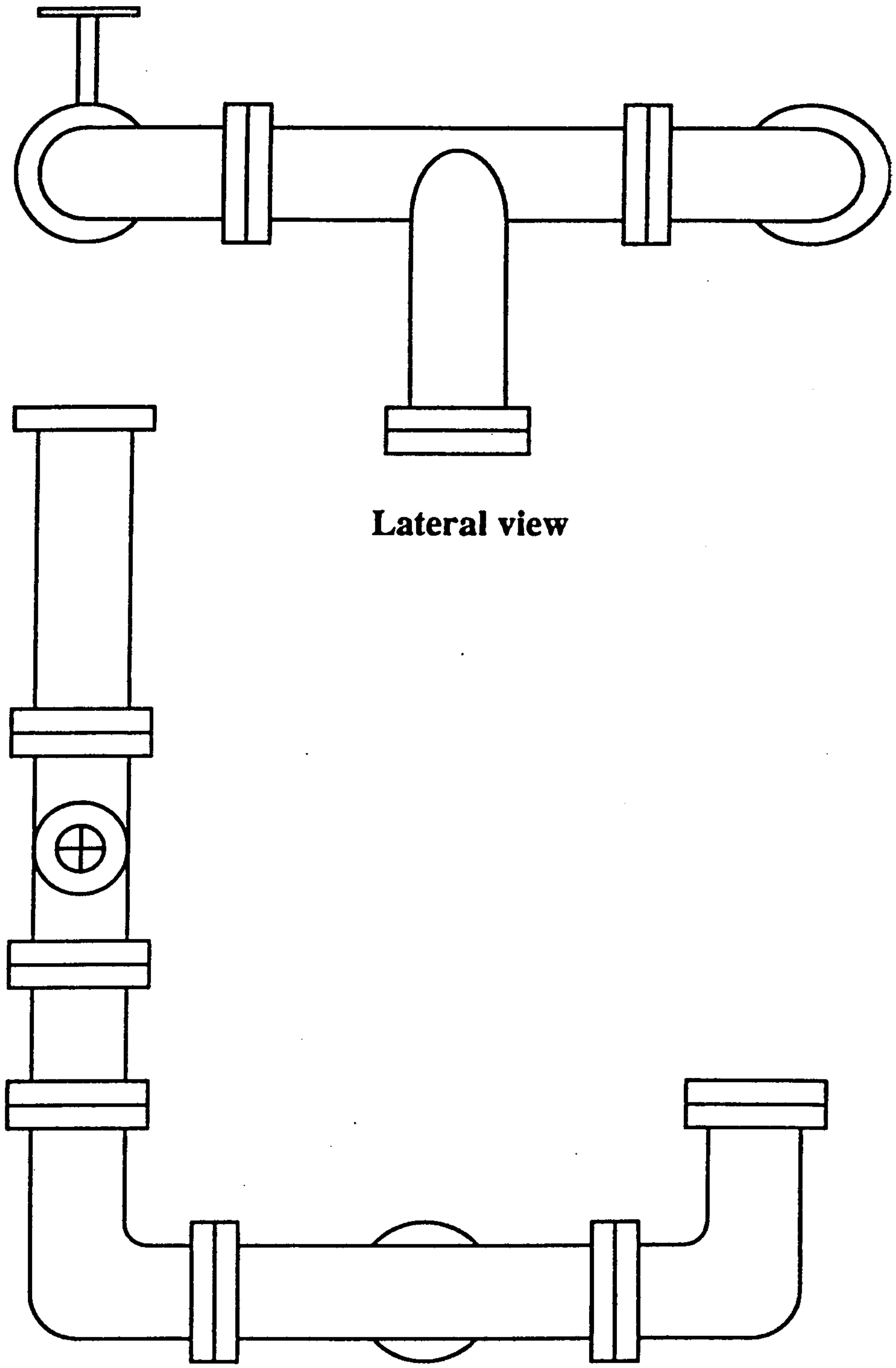

Figure 2. Multiviews of vent assembly used atop the 10000-gallon tank depicted in Figure 1; base of T-fitting bolts to tank flange; right leg of vent is capped such that GN2 flows only through the pipe and globe valve which comprise the left leg.